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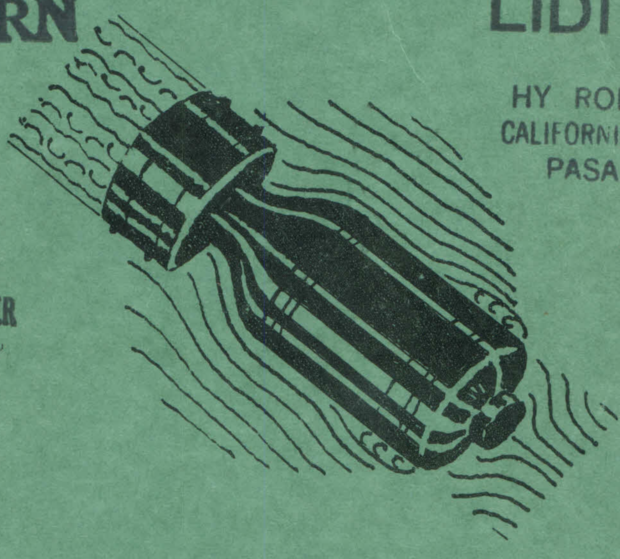
WATER TUNNEL TESTS OF THE MK13-1, MK13-2 and MK13-2A TORPEDOES WITH SHROUD RING TAILS.



THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA.

SECTION Nº 6.1 Sr 207-939
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OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE
DIVISION SIX — SECTION 6.1

WATER TUNNEL TESTS OF THE MK 13-1, MK 13-2, AND MK 13-2A TORPEDOES WITH SHROUD RING TAILS

BY

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THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRAULIC MACHINERY LABORATORY
PASADENA, CALIFORNIA

Section No. 6.1-sr-207-939
HML Rep. No. ND-15.1

Report Prepared by
Joseph Levy
Hydraulic Engineer

November 24, 1943

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INTRODUCTION

The High Speed Water Tunnel is operated by the California Institute of Technology under Contract OEMsr-207 with the office of Scientific Research and Development and is sponsored by Division 6, Section 6.1 of the National Defense Research Committee.

This report covers a series of preliminary water tunnel tests of a model of the Mk 13-1, 13-2, and 13-2A torpedoes with shroud ring tails added, and is a supplement to a previous report of this laboratory, entitled "Water Tunnel Tests of the Mk 13-1, Mk 13-2, and Mk 13-2A Torpedoes," file marked Section No. 6.1-sr-207-936, and dated November 9, 1943. In the course of the investigation covered by the latter report, it was found that the torpedoes of this series are highly unstable and that they are controllable only within an extremely narrow range of angles of attack. The tests reported herein were, therefore, suggested by this laboratory, and were authorized by Dr. W. V. Houston, Director, Special Studies Group, Columbia University, Division of War Research.

The objects of these tests were to investigate the possibilities for improving the stability and controllability of these torpedoes by the use of shroud ring tails, and to discover the trends of variation of these characteristics with variations of the several design factors of the shroud rings. Nine different shroud rings were tested with the torpedo model. It was found that marked improvement of the stability and control angle of these torpedoes may be obtained, without appreciable detriment to other characteristics, by the addition of shroud ring tails. The trends of variation of the stability, control angle, rudder effect, and drag of the torpedo with variations of the shroud ring design were clearly brought out. The results of these tests are shown in Figures 11 to 19, 21 and 22, and are summarized on pages 9 and 10 of this report.

WATER TUNNEL TESTS
OF THE
MK 13-1, MK 13-2, AND MK 13-2A TORPEDOES

I. PURPOSE AND SCOPE OF THE INVESTIGATION

This report covers a series of water tunnel tests of the U. S. Navy Torpedo Mk 13, Modifications 1, 2, and 2A, with shroud ring tails added, and is a supplement to our report, Section No. 6.1-sr-207-936, entitled "Water Tunnel Tests of the Mk 13-1, Mk 13-2, and Mk 13-2A Torpedoes" dated November 9, 1943. The tests were made on models in the High Speed Water Tunnel at the California Institute of Technology.(1)

These tests represent a preliminary investigation of the possibility of improving the stability and control angle of these torpedoes by the use of shroud ring tails. The specific objectives of this study were to determine the effect of shroud tails on the stability, control angle, rudder effect, and drag of the torpedoes, and to discover the trends of variation of these characteristics with variations of the several design factors of the shroud rings. Nine shroud rings were tested. With each ring pitching tests were made with horizontal rudder settings of 0, 5, and 10 degrees down.

A description of the test equipment and test procedures will be found in Appendix A. Definitions and symbols are given in Appendix B.

II. DESCRIPTION OF THE MODELS

The Mk 13-1, Mk 13-2, and Mk 13-2A torpedoes, being exactly alike in external shape, may be represented by a single model. To accommodate shroud rings of different cone angles, three model afterbodies were made with the fins of each afterbody modified to receive interchangeable rings of one cone angle. The series of shroud rings investigated is as follows:

(1) Cylindrical shrouds of 1-1/4", 7/8", and 1/2" widths

(2) Conical shrouds, 8° cone angle, of 1-1/4", 7/8", and 1/2" widths

(3) Conical shrouds, 16° cone angle, of 1-1/4", 7/8", and 1/2" widths

(1) Figures refer to references listed at end of this report.

The cone angle is defined as the included angle between the inner chords of the ring on an axial crossection, as shown in Figure 1.

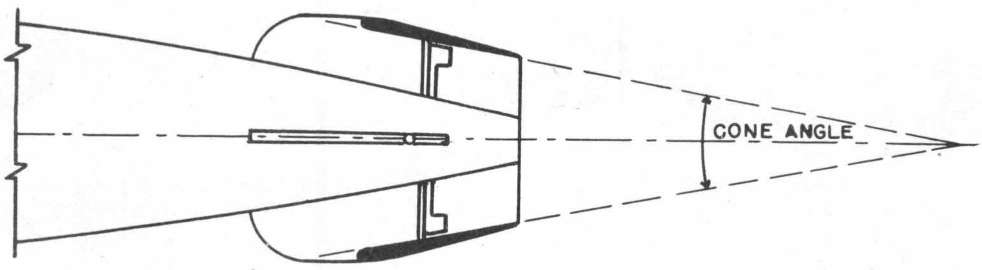


FIGURE 1

The model dimensions of 1-1/4", 7/8", and 1/2" shroud widths correspond to full-scale widths of 14", 9.80", and 5.60", respectively (model scale ratio of 1 to 11.21). The maximum outside diameter of each ring is the same as the maximum diameter of the torpedo. The profile of each shroud ring, in crossection, is an approximation to the profile of an airfoil with a linear inner surface, a maximum full-scale thickness of 1/2", and a trailing edge thickness of 1/8". The widest rings were set with their trailing edges flush with the tail end of the torpedo, and their foreparts rabbetted into and attached to the fins. The leading edges of the narrower rings were set in the same position as those of the widest.

To expedite the manufacture of these models, the horizontal rudders alone were made movable. The vertical rudders are fixed in neutral position. Also, these rudders were not made with the high degree of precision normally used in the construction of water tunnel models. Slight inconsistencies in the test results may, therefore, be attributed to this cause. However, the results show that, on the whole, the models were quite satisfactory for the purposes of these tests.

Figures 2 to 4 show the model assembled with the three afterbodies, each with its three interchangeable rings. Figures 5 and 6 are oblique views of the model with the 8° conical ring of 1/2" width. Figures 7 to 9 give details of the three afterbodies and nine shrouds. Figure 10 shows the overall dimensions of the model without shrouds.

FIGURE 2

MODEL WITH 16^{0} CONICAL RINGS

1-1/2" RING INSTALLED

FIGURE 3

MODEL WITH CYLINDRICAL RINGS

7/8" RING INSTALLED

FIGURE 4

MODEL WITH 8° CONICAL RINGS

1/2" RING INSTALLED

NOTE THAT VERTICAL RUDDERS ARE COMPLETELY EXPOSED WHILE HORIZONTAL RUDDERS ARE PARTLY EXPOSED.

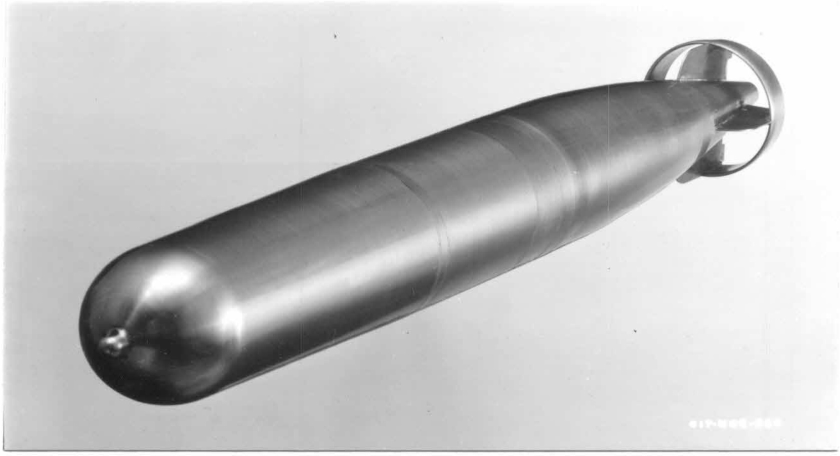


FIGURE 5

FIGURE 6

TWO VIEWS OF MODEL WITH

8° CONICAL RING OF 1/2" WIDTH

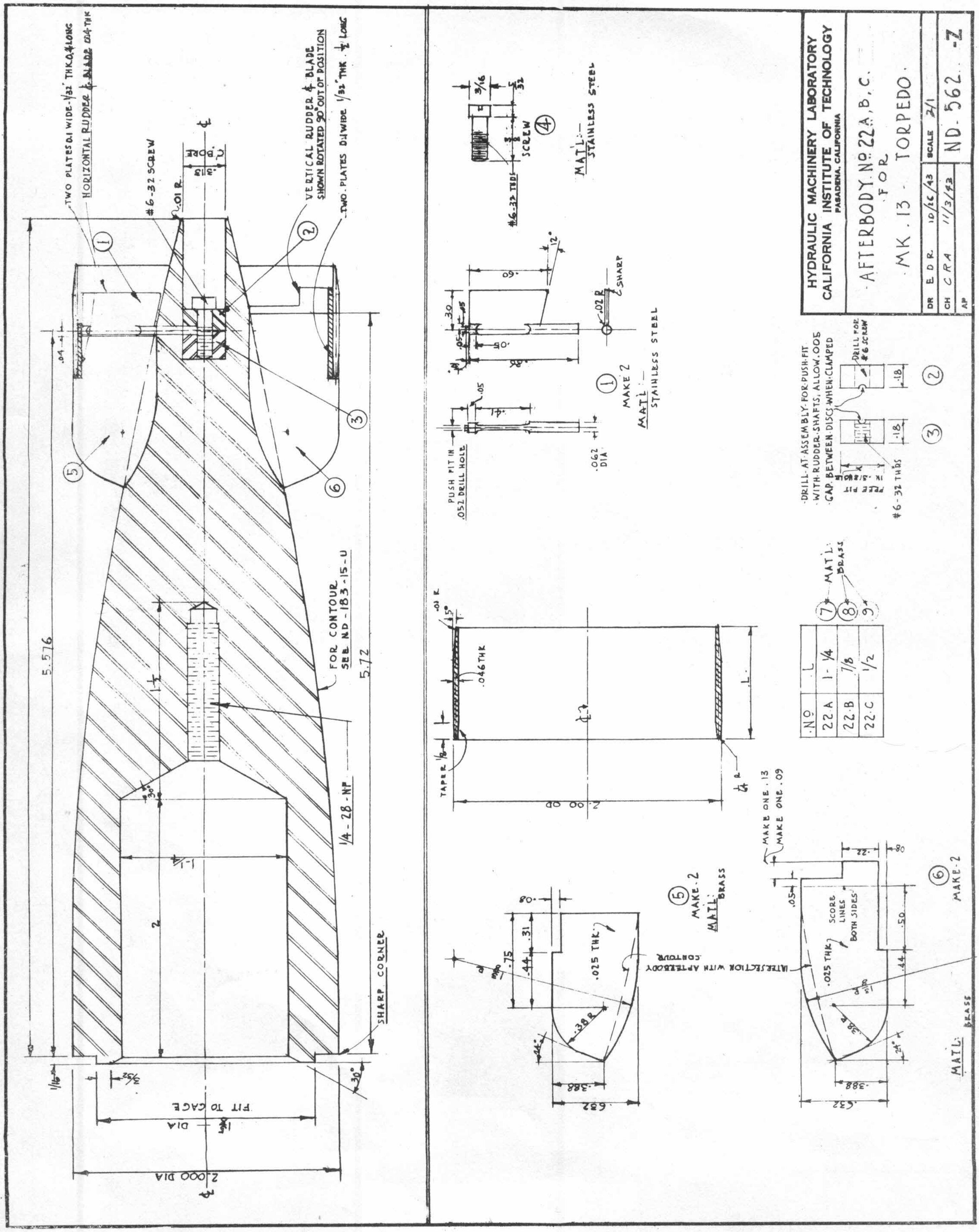
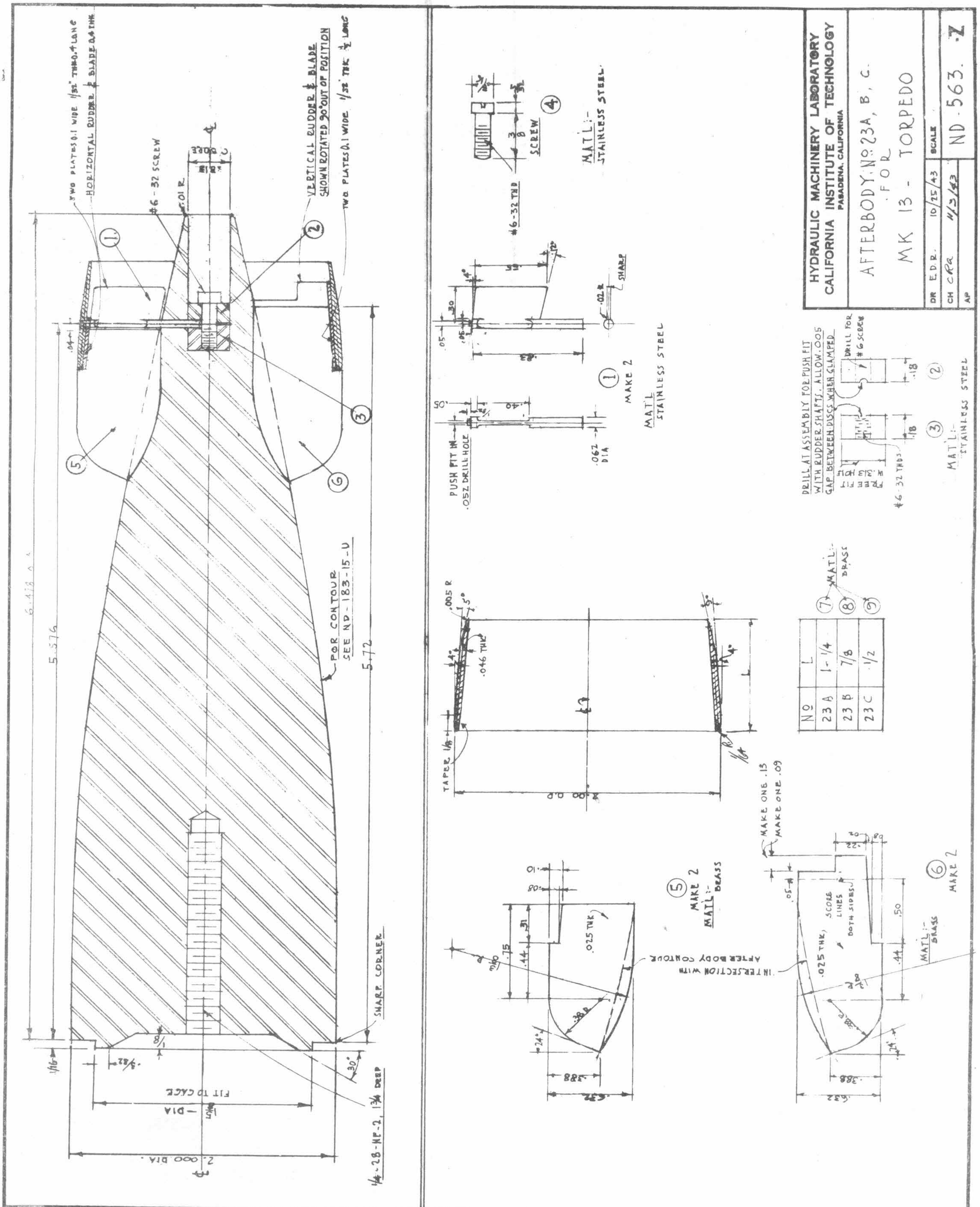

HYDRAULIC MACHINERY LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
AFTERBODY No 22A, B, C.
FOR
MK. 13 TORPEDO.
ND. 562 -Z
DR E D R 10/26/43
CH C R A 11/3/43
SCALE 2/1
No | L
22A | 1-1/4
22B | 7/8
22C | 1/2
MAT'L: STAINLESS STEEL
MAT'L: BRASS
FOR CONTOUR SEE ND-183-15-U
SHARP CORNER
FIT TO GAGE
2.000 DIA
5.576
5.72
1/4-28-NF
#6-32 SCREW
VERTICAL RUDDER & BLADE SHOWN ROTATED 90° OUT OF POSITION
HORIZONTAL RUDDER & BLADE
INTERSECTION WITH AFTERBODY CONTOUR
SCORE LINES BOTH SIDES
MAKE ONE .13
MAKE ONE .09
DRILL AT ASSEMBLY FOR PUSH FIT WITH RUDDER SHAFTS. ALLOW .005 GAP BETWEEN DISCS WHEN CLAMPED
PUSH FIT IN .052 DRILL HOLE
MAKE 2

FIGURE 7



Nº	L
23 A	1 - 1/4
23 B	7/8
23 C	1/2

FIGURE 8

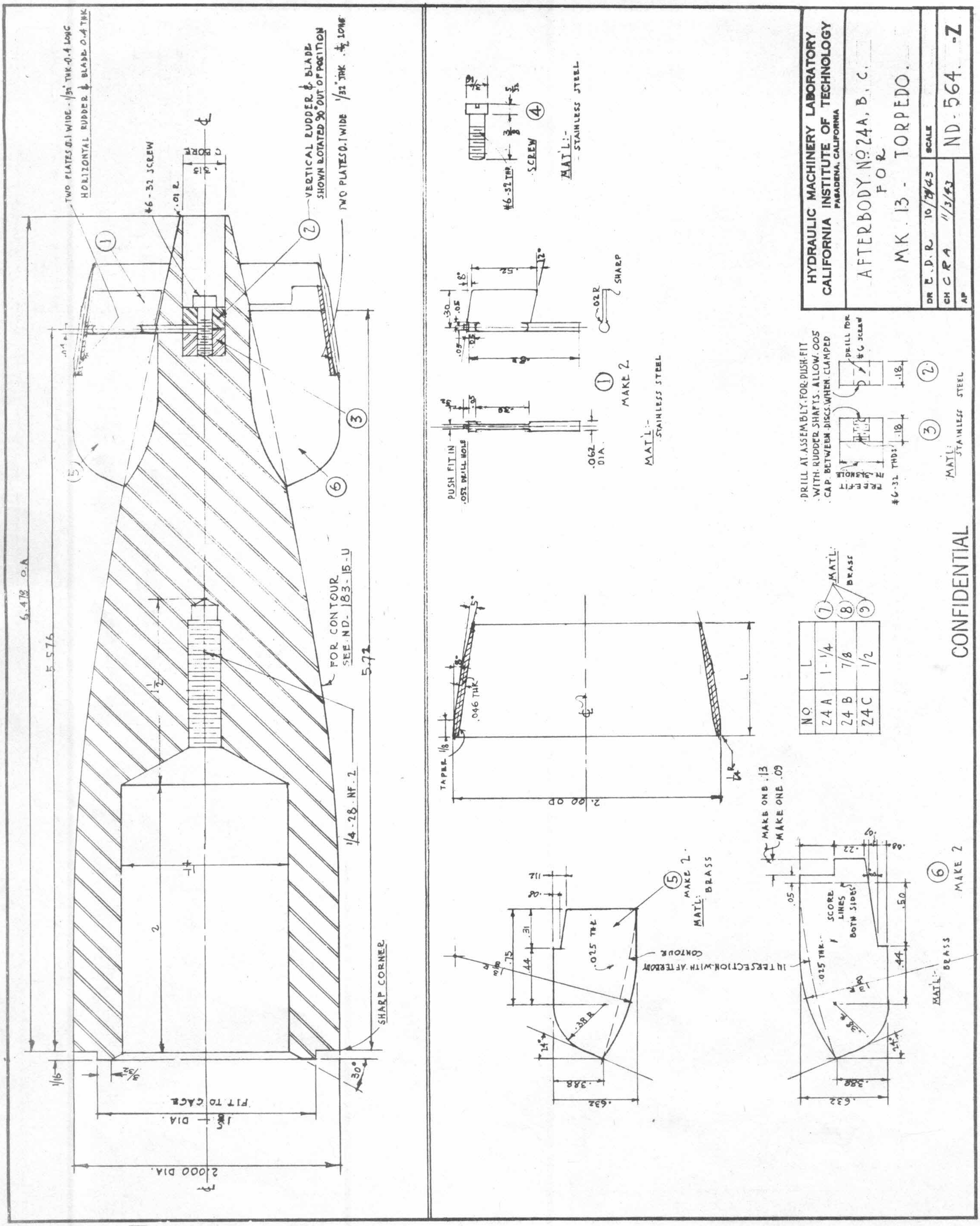
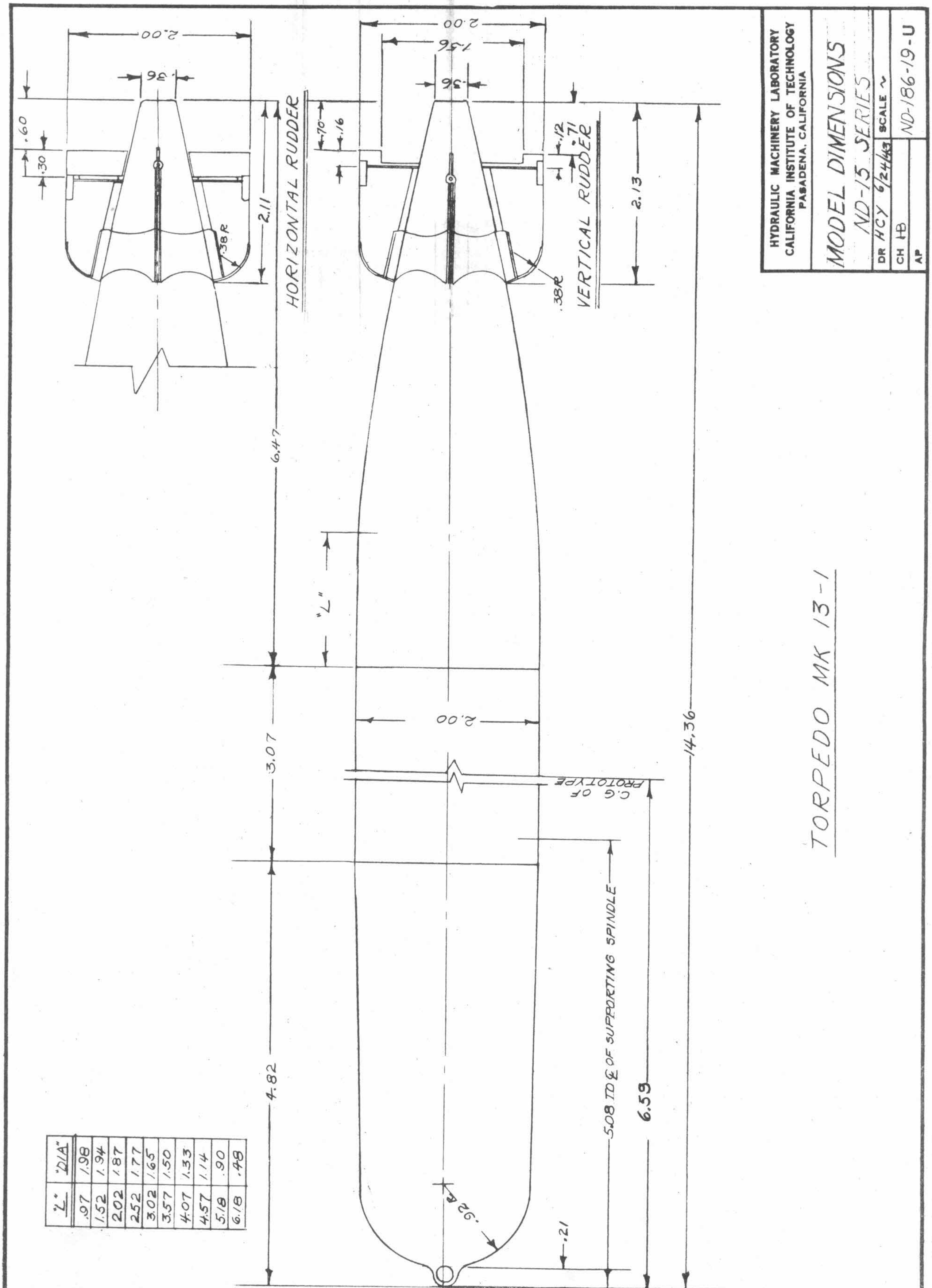

HYDRAULIC MACHINERY LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
AFTERBODY No 24A, B, C,
FOR
MK. 13 - TORPEDO.
SCALE
ND. 564. -Z
CONFIDENTIAL
SHARP CORNER
FIT TO CAGE
2.000 DIA.
FOR CONTOUR SEE ND-183-15-U
1/4-28 NF. 2
SCREW
MAT'L:- STAINLESS STEEL
MAKE 2
MAT'L: BRASS
SCORE LINES BOTH SIDES
INTERSECTION WITH AFTERBODY CONTOUR
DRILL AT ASSEMBLY FOR PUSH FIT WITH RUDDER SHAFTS. ALLOW .005 CAP BETWEEN DISCS WHEN CLAMPED
VERTICAL RUDDER & BLADE SHOWN ROTATED 90° OUT OF POSITION
NO. | L
24 A | 1-1/4
24 B | 7/8
24 C | 1/2

FIGURE 9



"L"	"DIA"
.97	1.98
1.52	1.94
2.02	1.87
2.52	1.77
3.02	1.65
3.57	1.50
4.07	1.33
4.57	1.14
5.18	.90
6.18	.48

FIGURE 10

III. TEST DATA

The results of these tests are presented in Figures 11 to 19, inclusive. Each of these sheets shows the hydrodynamic characteristics of the torpedo with one of the shroud tails. For comparison, there are also shown on each sheet the characteristics of the torpedo without shroud ring for horizontal rudder settings of 0 and 10 degrees.

The data presented in this report have been corrected for support shield interference only (i.e., the data represent model test results and not prototype performance) and, therefore, are not directly applicable to the prototype torpedoes. It was felt that the desired objectives and comparisons could be attained satisfactorily with the unextrapolated model results.

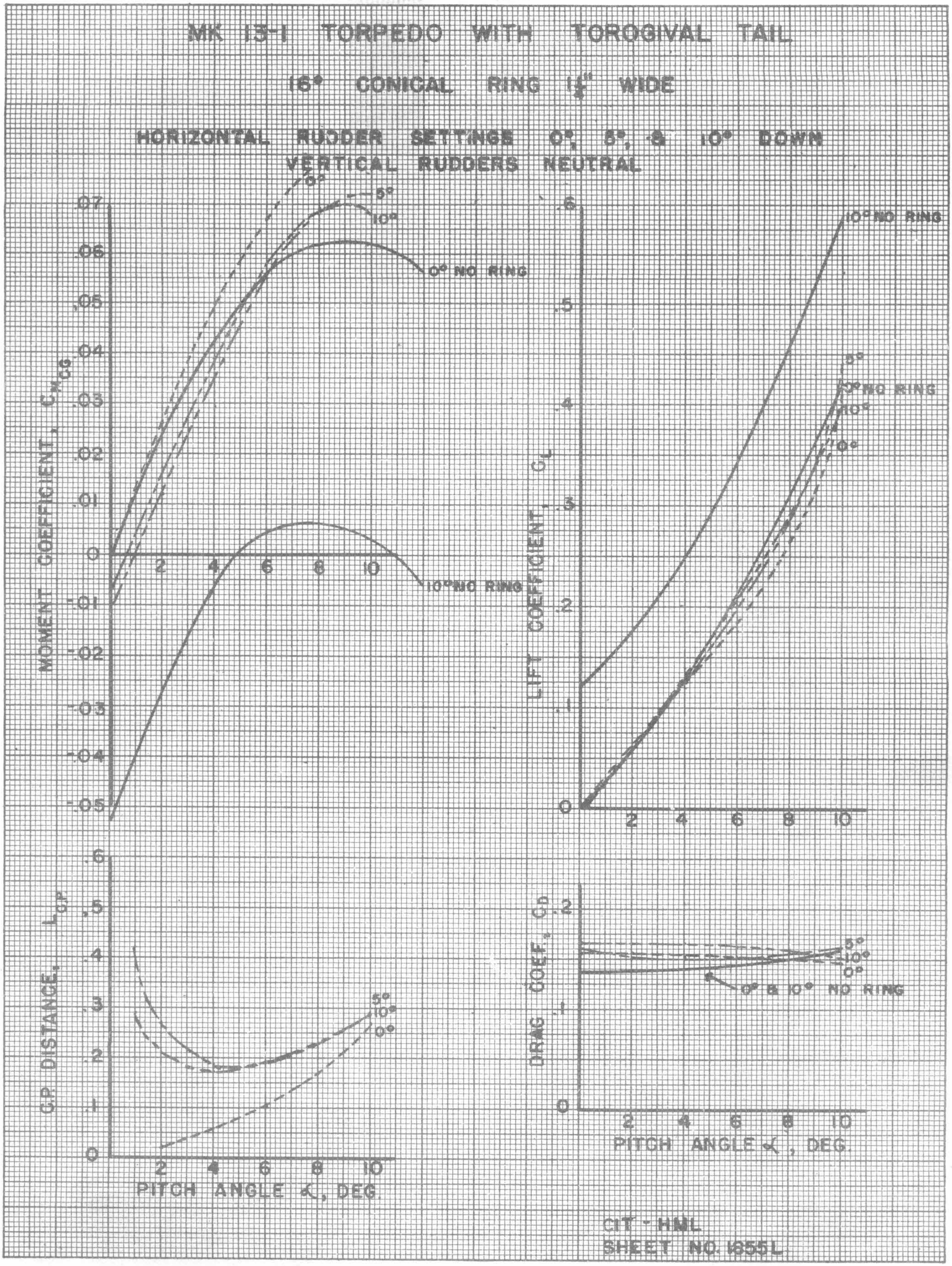

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
16° CONICAL RING 1¼" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5°, & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{M_{CG}}$
0° NO RING
10° NO RING
LIFT COEFFICIENT, C_L
DRAG COEF., C_D
0° & 10° NO RING
C.P. DISTANCE, $L_{C.P.}$
PITCH ANGLE α, DEG.
CIT - HML
SHEET NO. 1655L

FIGURE II

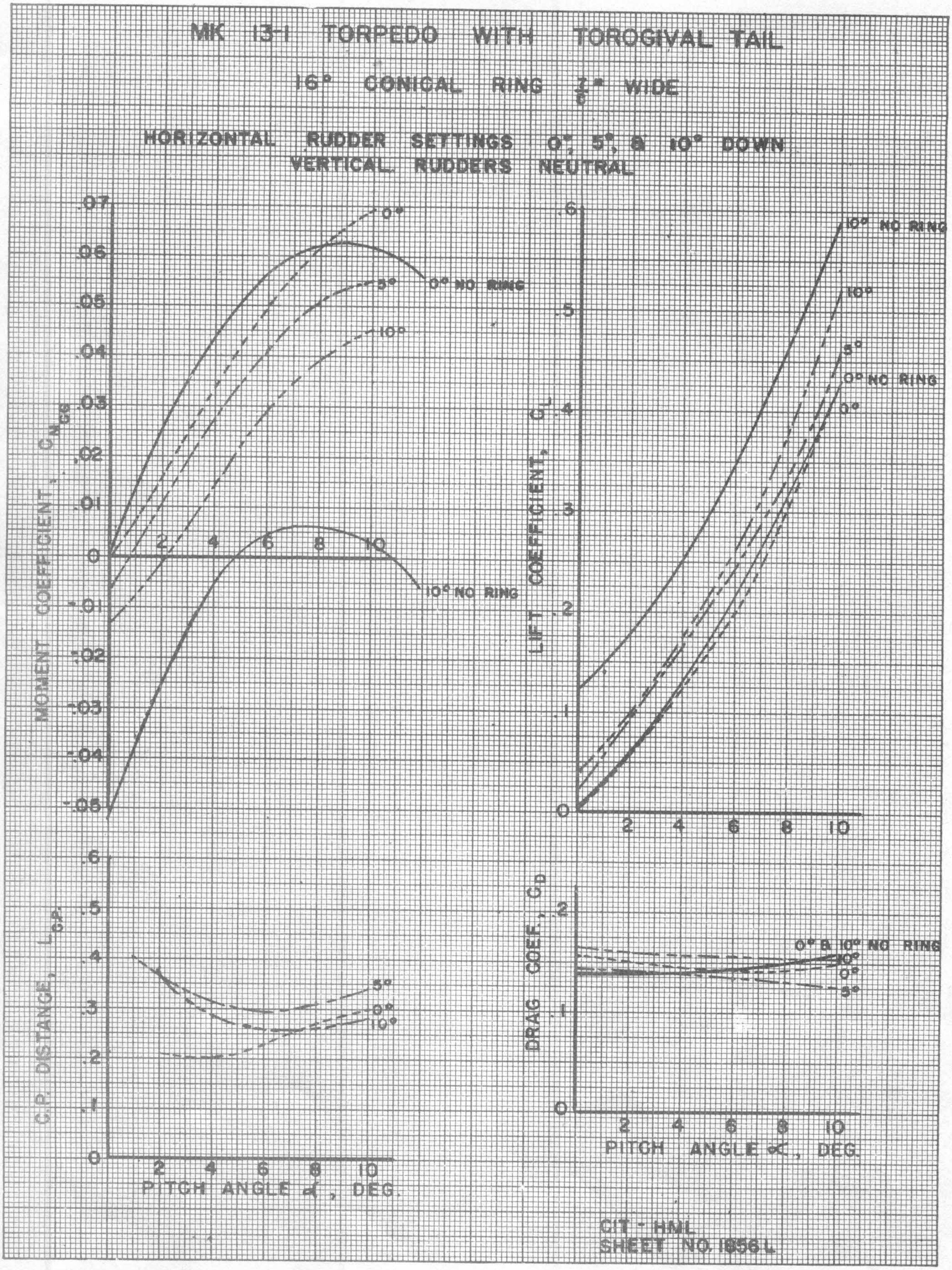

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
16° CONICAL RING 7/8" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5°, & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{N_{CG}}$
0°
5°
10°
0° NO RING
10° NO RING
LIFT COEFFICIENT, C_L
10° NO RING
10°
5°
0° NO RING
0°
C.P. DISTANCE, $L_{C.P.}$
5°
0°
10°
PITCH ANGLE α, DEG.
DRAG COEF., C_D
0° & 10° NO RING
10°
0°
5°
PITCH ANGLE α, DEG.
CIT - HML
SHEET NO. 1856 L

FIGURE 12

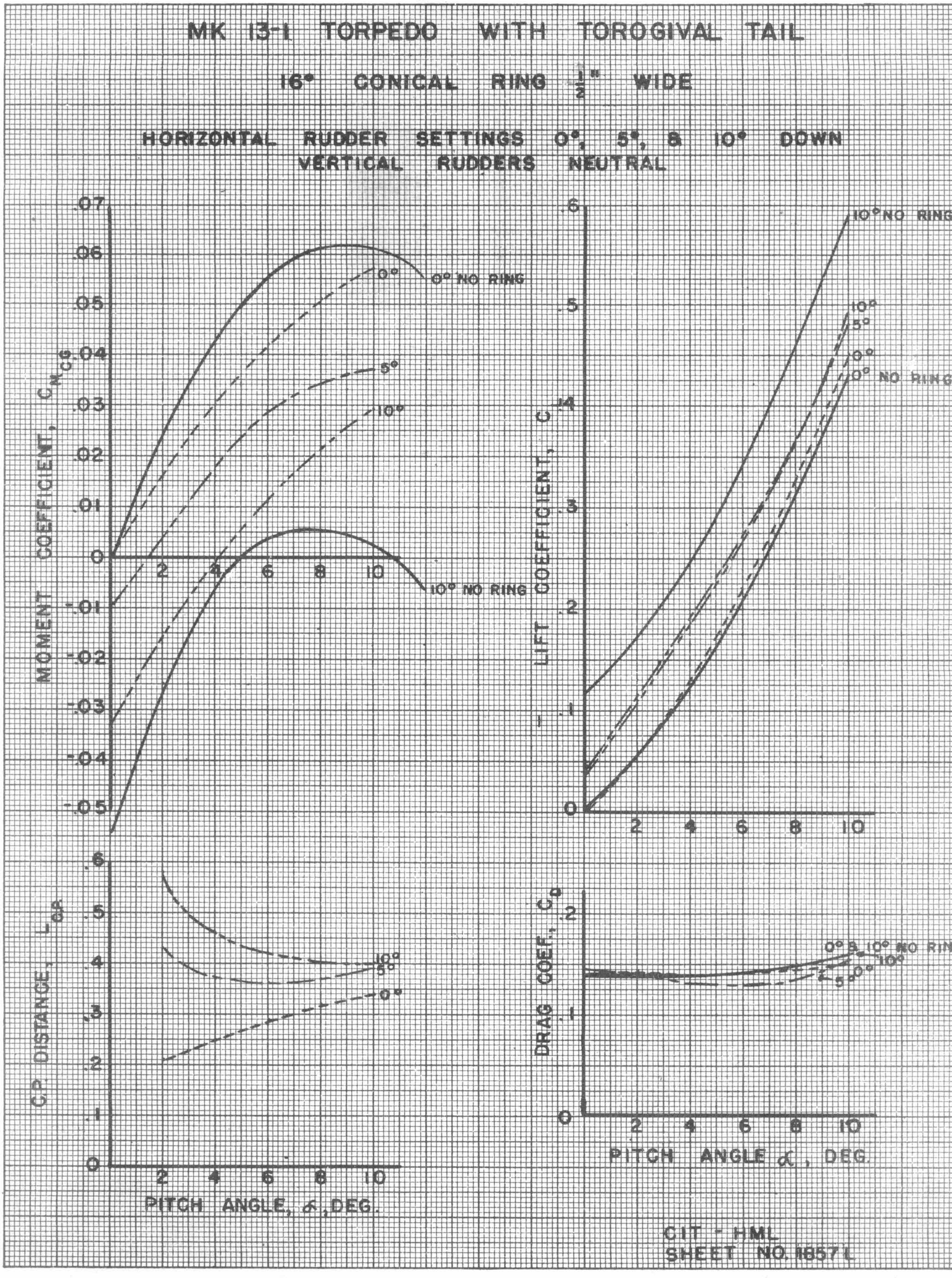

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
16° CONICAL RING ½" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5°, & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{M_{C.G.}}$
0° NO RING
0°
5°
10°
10° NO RING
LIFT COEFFICIENT, C_L
10° NO RING
10°
5°
0°
0° NO RING
C.P. DISTANCE, $L_{C.P.}$
10°
5°
0°
PITCH ANGLE, α, DEG.
DRAG COEF., C_D
0° & 10° NO RING
10°
5° 0°
PITCH ANGLE α, DEG.
CIT - HML
SHEET NO. 18571

FIGURE 13

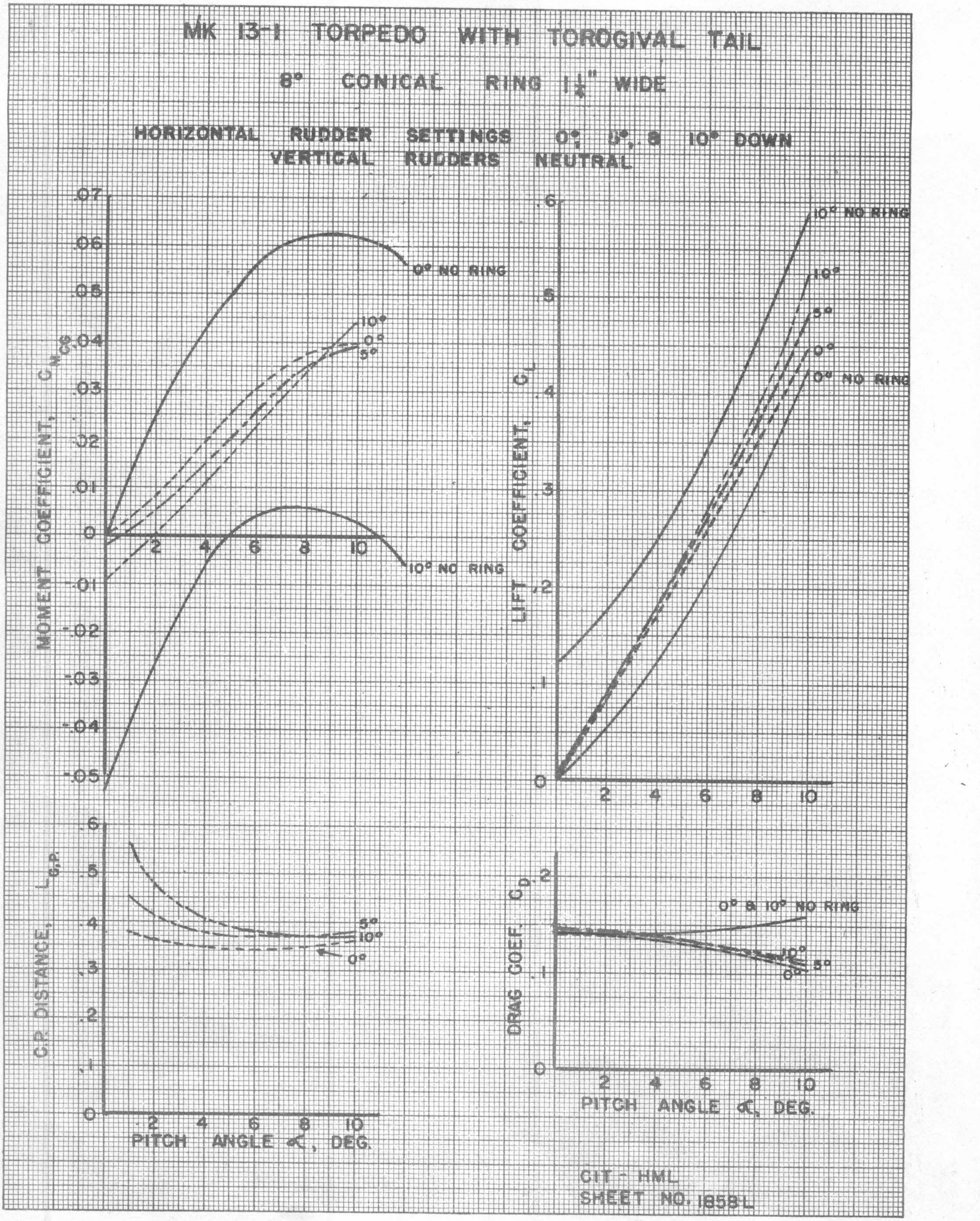

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
8° CONICAL RING 1¼" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5°, & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{M_{CG}}$
0° NO RING
10°
0°
5°
10° NO RING
LIFT COEFFICIENT, C_L
10° NO RING
10°
5°
0°
0° NO RING
C.P. DISTANCE, $L_{C.P.}$
5°
10°
0°
PITCH ANGLE α, DEG.
DRAG COEF. C_D
0° & 10° NO RING
10°
0°
5°
PITCH ANGLE α, DEG.
CIT - HML
SHEET NO. 1858L

FIGURE 14

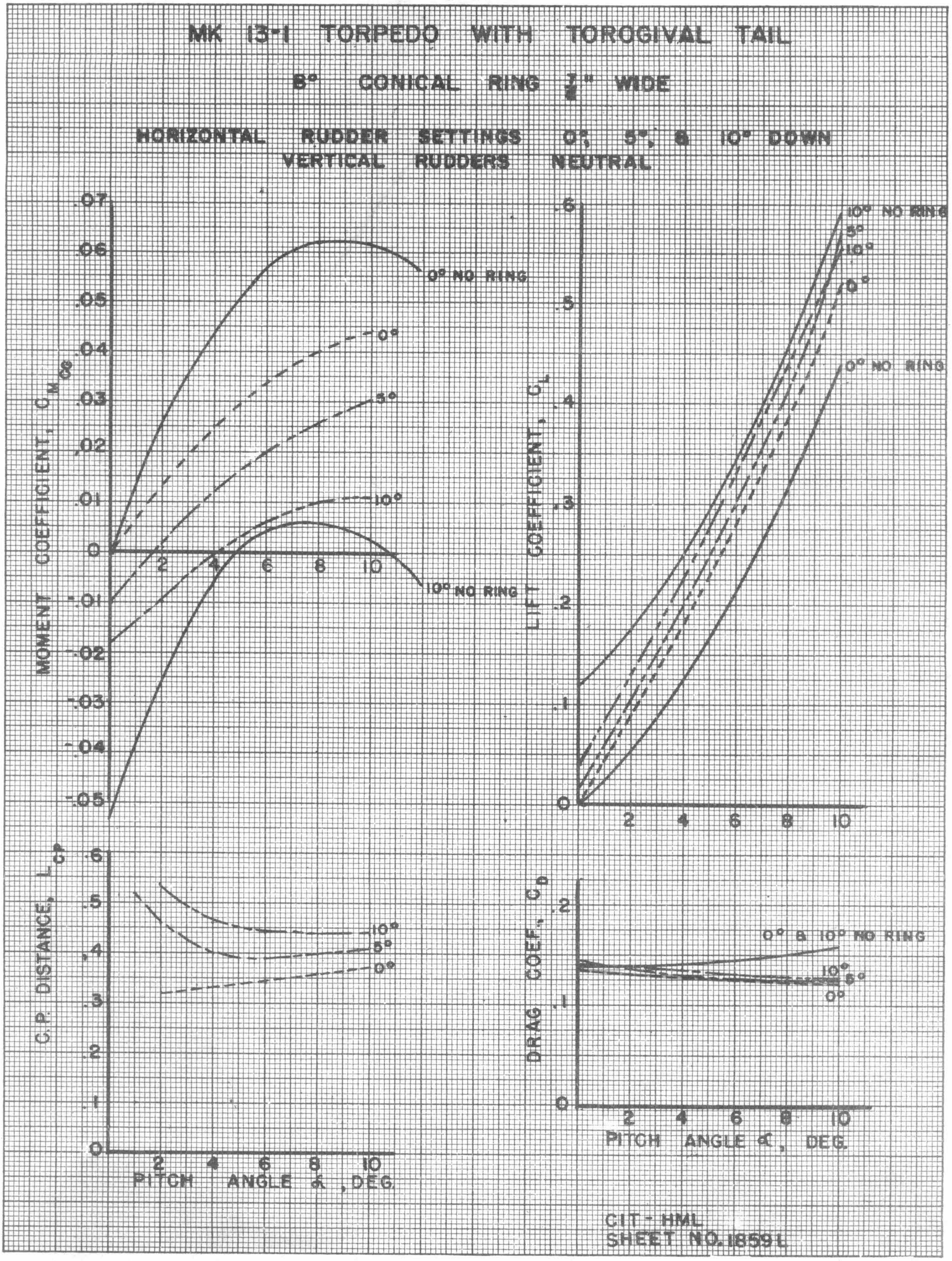

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
8° CONICAL RING 7/8" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5°, & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{M_{CG}}$
0° NO RING
0°
5°
10°
10° NO RING
LIFT COEFFICIENT, C_L
10° NO RING
5°
10°
0°
0° NO RING
C.P. DISTANCE, L_{CP}
10°
5°
0°
PITCH ANGLE α, DEG.
DRAG COEF., C_D
0° & 10° NO RING
10°
5°
0°
PITCH ANGLE α, DEG.
CIT - HML
SHEET NO. 1859 L

FIGURE 15

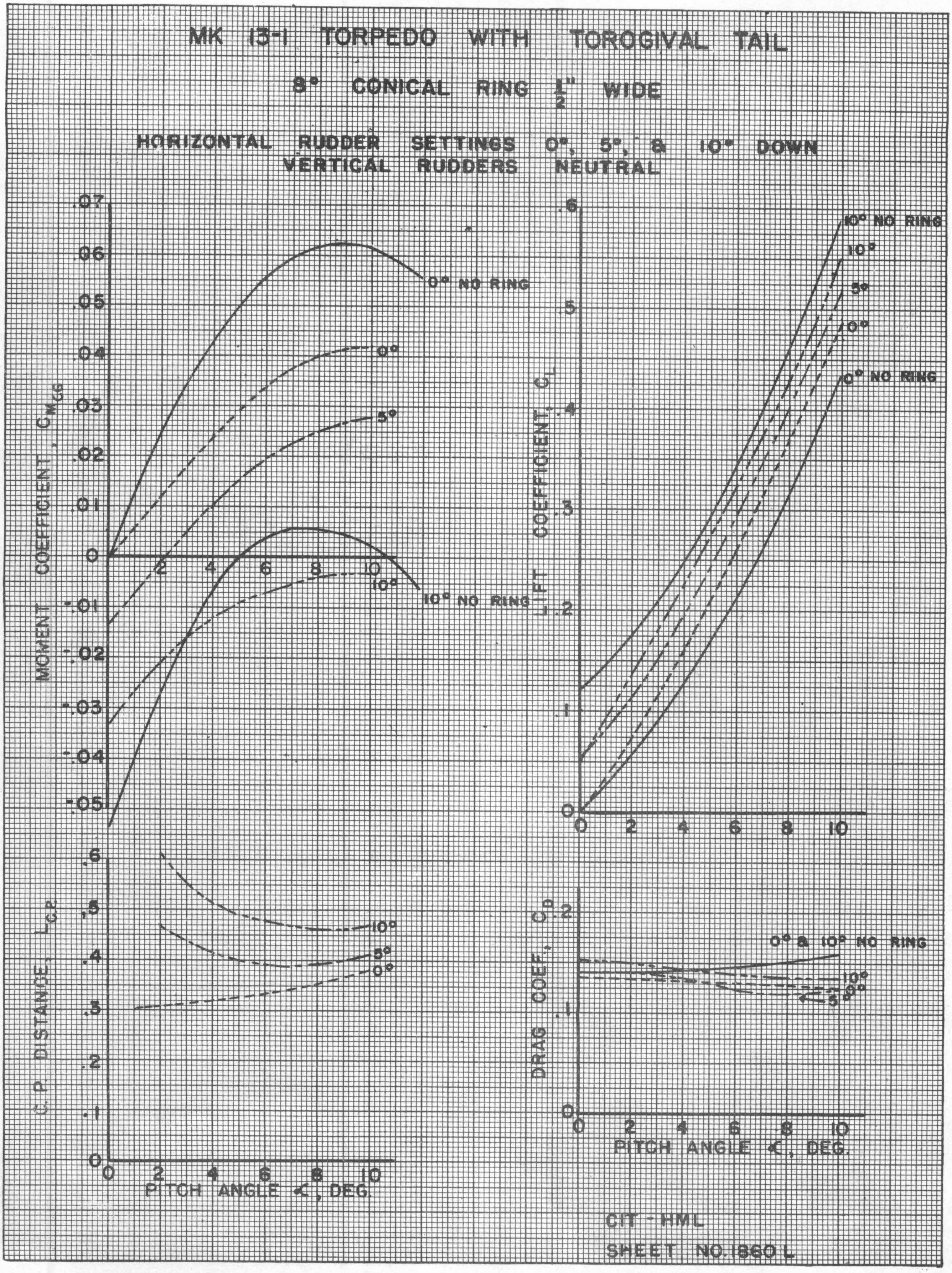

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
8° CONICAL RING ½" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5°, & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{M_{CG}}$
0° NO RING
0°
5°
10°
10° NO RING
LIFT COEFFICIENT, C_L
10° NO RING
10°
5°
0°
0° NO RING
C. P. DISTANCE, $L_{C.P.}$
10°
5°
0°
DRAG COEF, C_D
0° & 10° NO RING
10°
0°
5°
PITCH ANGLE α, DEG.
PITCH ANGLE α, DEG.
CIT - HML
SHEET NO. 1860 L

FIGURE 16

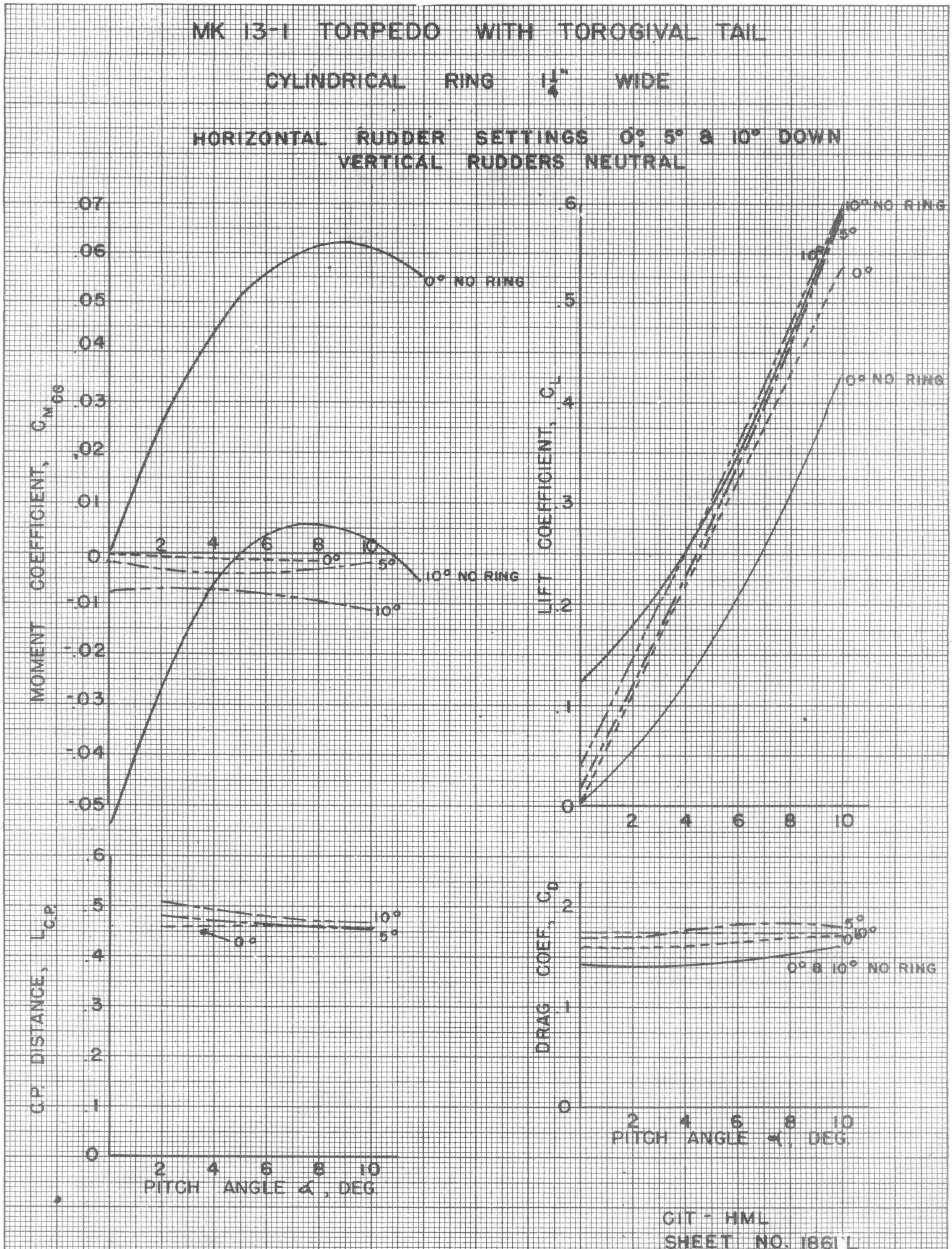

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
CYLINDRICAL RING 1¼" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5° & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{M_{CG}}$
0° NO RING
10° NO RING
0°
5°
10°
LIFT COEFFICIENT, C_L
10° NO RING
5°
10°
0°
0° NO RING
C.P. DISTANCE, $L_{C.P.}$
10°
5°
0°
DRAG COEF., C_D
5°
10°
0°
0° & 10° NO RING
PITCH ANGLE α, DEG
PITCH ANGLE α, DEG
CIT - HML
SHEET NO. 1861 L

FIGURE 17

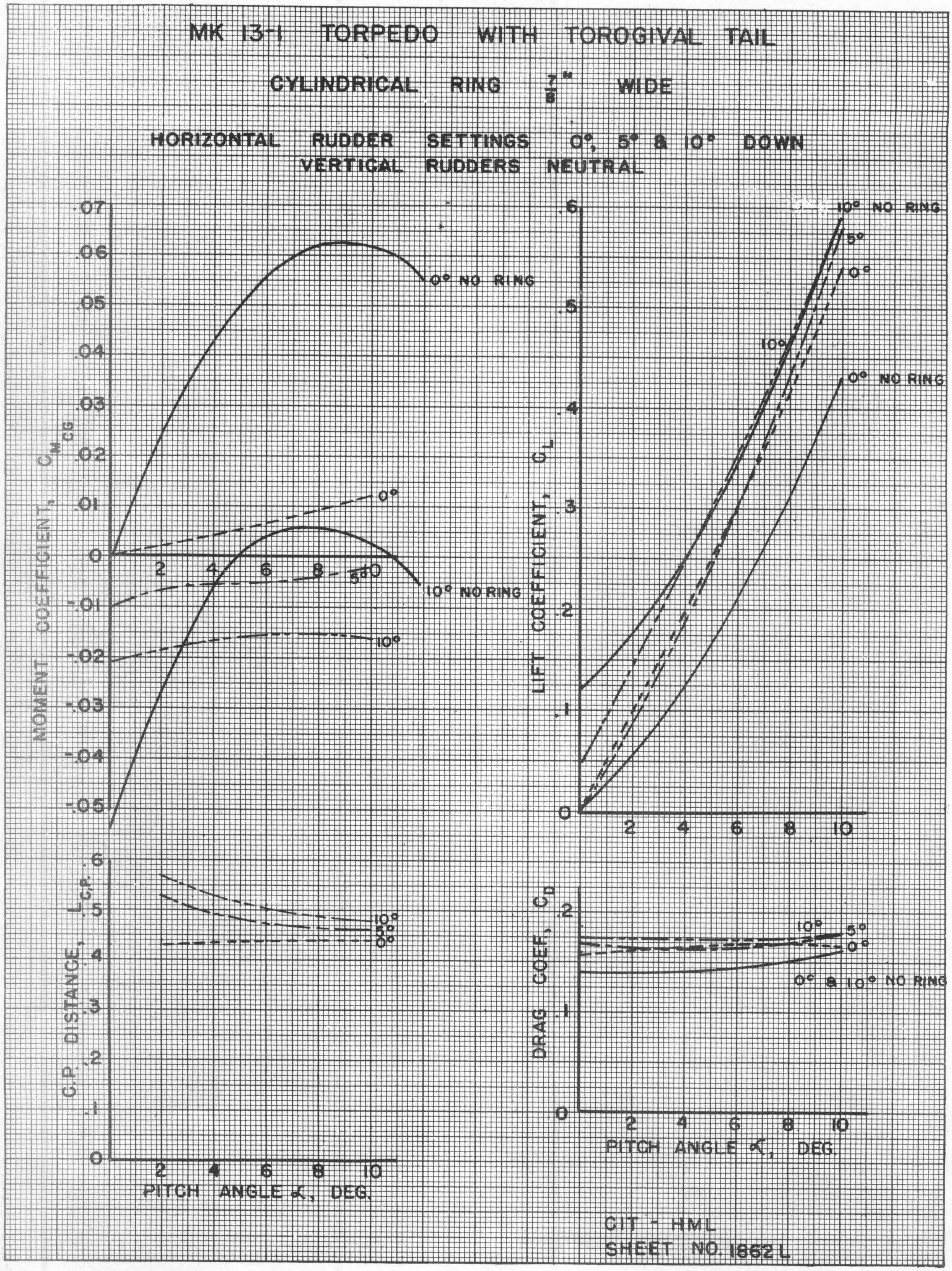

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
CYLINDRICAL RING 7/8" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5° & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{M_{CG}}$
0° NO RING
10° NO RING
0°
5°
10°
LIFT COEFFICIENT, C_L
10° NO RING
5°
0°
10°
0° NO RING
C.P. DISTANCE, $L_{C.P.}$
10°
5°
0°
DRAG COEF., C_D
10°
5°
0°
0° & 10° NO RING
PITCH ANGLE α, DEG.
PITCH ANGLE α, DEG.
CIT - HML
SHEET NO. 1862 L

FIGURE 18

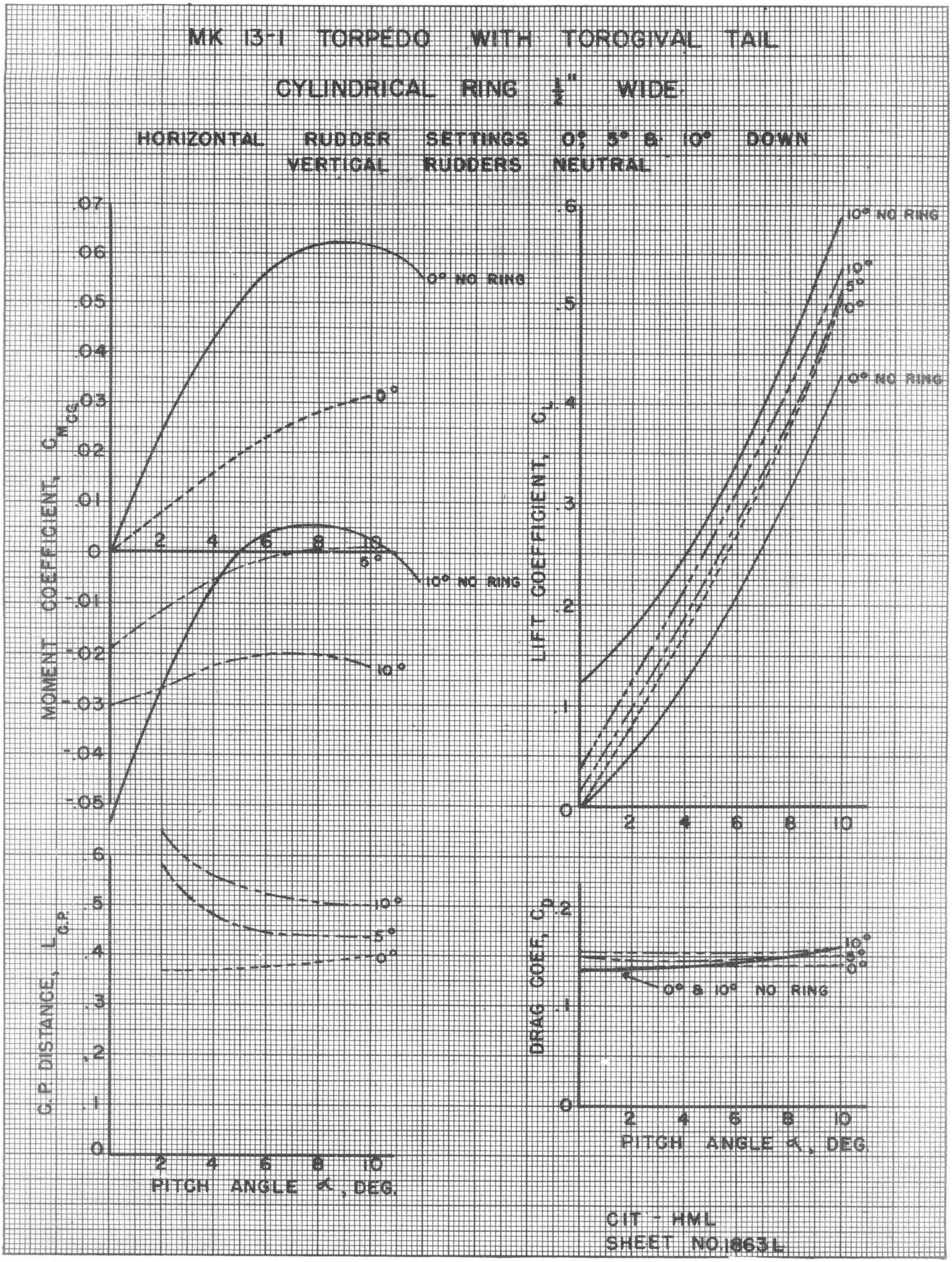

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
CYLINDRICAL RING ½" WIDE
HORIZONTAL RUDDER SETTINGS 0°, 5° & 10° DOWN
VERTICAL RUDDERS NEUTRAL
MOMENT COEFFICIENT, $C_{M_{C.G.}}$
0° NO RING
0°
5°
10°
10° NO RING
C.P. DISTANCE, $L_{C.P.}$
PITCH ANGLE α, DEG.
LIFT COEFFICIENT, C_L
DRAG COEF, C_D
0° & 10° NO RING
PITCH ANGLE α, DEG
CIT - HML
SHEET NO.1863L

FIGURE 19

IV. DISCUSSION OF TEST RESULTS

STATIC STABILITY

A projectile is said to be "statically" stable if it tends to return to equilibrium when disturbed, that is, if the moment resulting from the disturbance is a restoring moment. In a discussion of static stability, the actual motion following the perturbation is not considered at all. In fact, a projectile may oscillate about the equilibrium position without ever remaining in it. In this case the projectile would be statically stable even though it had zero or negative damping. Since the water tunnel tests were made under steady state conditions, the results give only the principal hydrodynamic forces but not the damping terms.

In accordance with the sign convention adopted, a projectile experiences a restoring moment when the angle of attack and the moment coefficient have opposite signs. Therefore, a negative slope of the moment curve at zero moment corresponds to static stability, and a positive slope corresponds to instability. The degree of stability or instability is measured by the magnitude of the slope. An examination of the curves of any one of Figures 11 to 19 shows that the torpedo without shroud ring tail is highly unstable.

Stability is an absolute necessity for a projectile which has no movable rudders. The torpedo, however, can maintain its depth or keep to a set course, in spite of its inherent instability, by moving the rudders so as to create a restoring moment whenever disturbed. It is not exactly known, at present, how much stability or instability is desirable in a torpedo. One possible advantage in instability may be that it quickens the rudder response, since any slight deviation from the course is immediately magnified to a size which will insure actuation of the steering engine. However, this result should be obtainable by other means without sacrificing stability. Stability, on the other hand, offers the advantage that the torpedo, when disturbed, tends to return to equilibrium even before the rudders respond. Another, and perhaps more important, consideration is the fact that a stable torpedo cannot, of its own accord, yaw out beyond the control angle, and if forced beyond the control angle, will return to it as soon as the external force is removed. Aside from the first consideration, it seems that a stable torpedo should steer just as well as an unstable one having the same control angle and rudder effect.

CONTROL ANGLE

The term "control angle" may be defined as the maximum angle of attack within which the projectile can produce either a positive or negative moment by turning its rudders one way or the other. Outside the control angle the projectile is no longer under control of its rudders, but behaves in accordance with its inherent stability characteristics. With all other factors constant, the magnitude of the control angle depends on the maximum rudder setting obtainable. For convenience in this discussion we may use, as a measure, the control angle corresponding to a maximum rudder setting of 10 degrees. Also, the effects of static moments due to trim, and forces due to excess of weight over buoyancy, will be neglected.

The characteristics of the Mk 13-1 torpedo may be used to illustrate the behavior of an unstable projectile beyond the control angle. The solid-line curves on Figures 11 to 19 show that this torpedo without shroud ring has a control angle in the vertical plane of about 5 degrees. At the limit of the control angle the torpedo is unstable because the slope of the moment curve is positive. At a larger pitch angle, say + 6 degrees, the moment is positive regardless of the rudder setting. Since a positive moment tends to increase a positive angle, the pitch angle will continue to increase until a stable condition is reached at a pitch angle of 10.8 degrees. The torpedo will then maintain this angle between its axis and its path as long as the rudder setting remains unchanged, and will travel on a circular path. The radius of the path is determined by the speed, the masses (real and virtual), the lift force, and the radial component of the propeller thrust. The effect of a change in rudder setting will be only to change the radius of the circular path, but the rudders will be unable to return the torpedo to straight-line motion. Therefore, for an unstable projectile it is necessary that the control angle be large enough to take care of all exigencies that might occur during the run.

The behavior of a stable projectile may be illustrated with the aid of Figure 20, which shows arbitrary moment characteristics of such a projectile. Within the control angle, up rudder produces a positive moment, causing the pitch angle to increase to the limit of the control angle where stability is reached. The pitch angle, therefore, will not increase any further except under the influence of some external force. Outside the control angle the moment is negative for all rudder settings so that the projectile tends to return to within the control angle. The term "control angle", therefore, does not have exactly the same meaning in the case of a stable projectile as it does in the case of an unstable one. In the latter case the projectile goes out of control beyond the control angle, whereas in the former

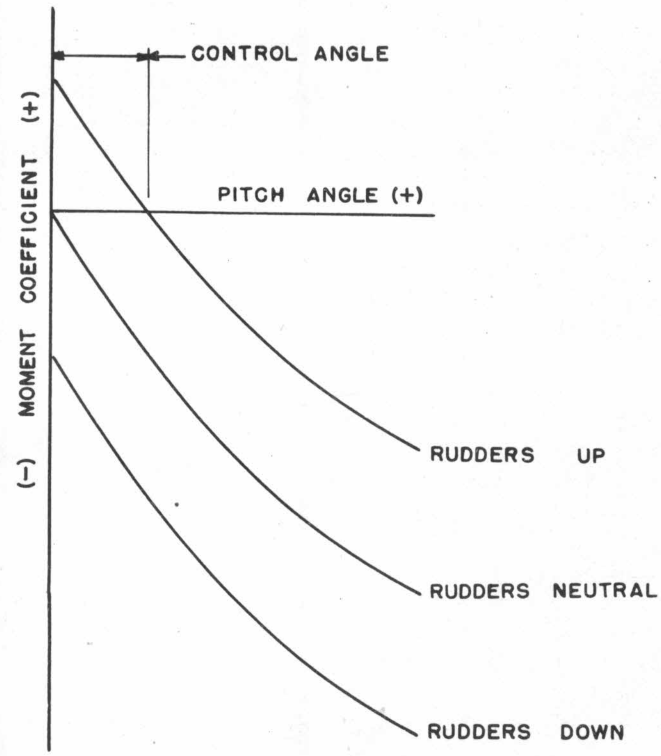


FIGURE 20

it does not. The control angle of a stable projectile merely detetermines the minimum radius of path obtainable. For this reason, it is desirable to have a reasonably large control angle even for a stable projectile, especially when it may be launched at an angle to the desired line of travel.

RUDDER EFFECT

The term "rudder effect" may be defined as the change in the moment coefficient produced by a given change in rudder setting. In this discussion, the rudder effect will be taken as the change in the moment coefficient at zero pitch produced by moving the rudders from neutral to ten degrees down.

EFFECT OF SHROUD ANGLE ON STABILITY

The effect of shroud cone angle on the stability of the torpedo is clearly brought out in Figure 21. Each of the three upper diagrams shows a comparison of the moment characteristics of the torpedo with neutral rudders for the three rings of same width but of different cone angle. The lower diagrams give the same comparisons for rudder settings of ten degrees down. The upper left-hand diagram shows that, with the 1-1/4" rings, the 16° conical shroud makes the torpedo even more unstable than it is without shroud; the 8° conical shroud reduces the instability to less than half its value without ring; and the cylindrical ring produces neutral stability. The stability of the torpedo, therefore, improves with decreasing cone angle. The same trend of variation of stability with cone angle is shown in the other diagrams of Figure 21.

MK 13-1 TORPEDO WITH TOROGIVAL TAIL
EFFECT OF SHROUD CONE ANGLE ON STABILITY
VERTICAL RUDDERS NEUTRAL

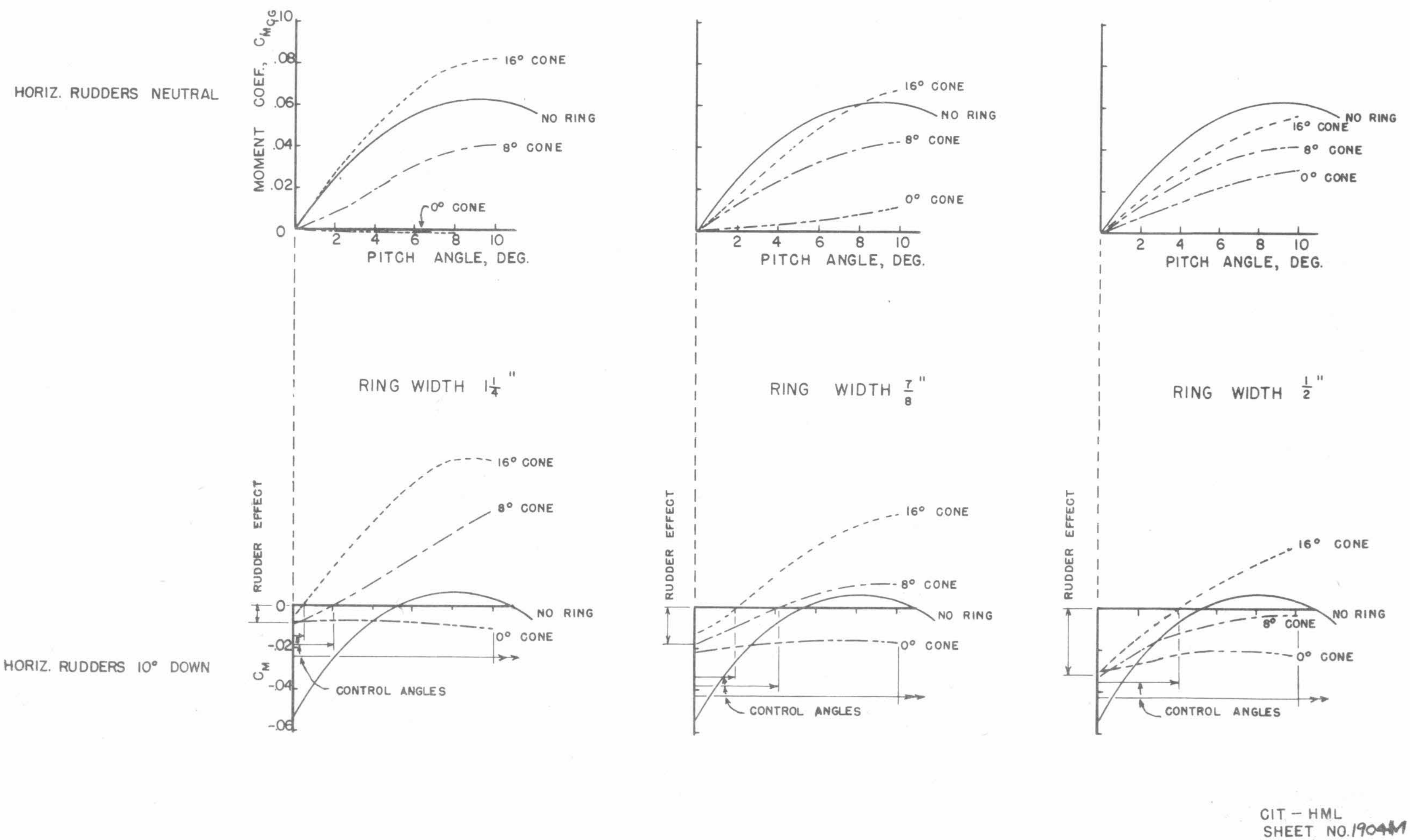


FIGURE 21

EFFECT OF SHROUD WIDTH ON STABILITY

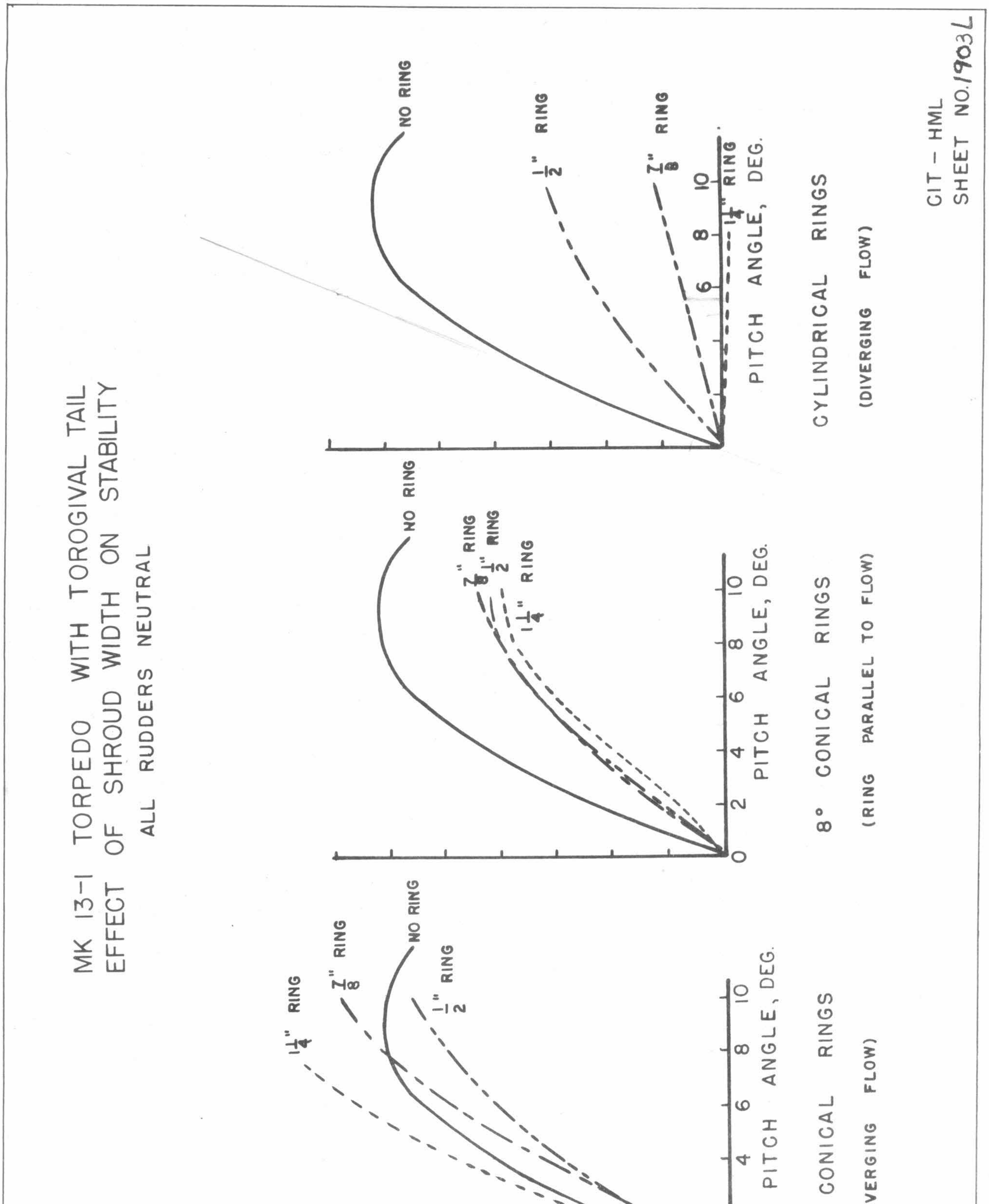
Each of the three diagrams of Figure 22 shows a comparison of the moment characteristics of the torpedo with neutral rudders for the three rings of same cone angle but of different width. It is seen that, with the 16° conical shroud, the stability of the torpedo increases with decreasing ring width. With the 8° conical rings, stability is nearly independent of the width of the ring. With the cylindrical shrouds, the stability of the torpedo decreases with decreasing ring width. It is of interest to note that the 8° cone angle was selected to fit the flow lines about the torpedo. Studies made in the Polarized Light Flume on a model without shroud ring showed that the flow lines near the outer edges of the fins are convergent and make an angle of 4° with the centerline of the torpedo. Apparently, when the ring fits the flow lines, its width has little effect on the stability, and when it does not fit the flow lines, the direction of the effect of ring width on stability depends on whether the ring increases or decreases the convergence of the flow lines, i.e., when the ring causes the flow to converge, stability decreases with increasing ring width; and when the ring causes the flow to diverge, stability increases with increasing ring width.

It should be noted here that the tests were made on a model without propellers. On a propeller driven torpedo, the flow lines on the afterbody may be expected to converge more rapidly. In order to produce the same effect, therefore, shroud rings on propeller driven torpedoes should have a somewhat larger cone angle than the rings tested on the model.

EFFECT OF SHROUD ON THE DRAG

Any improvements in stability and control angle that are accompanied by a large increase in the drag coefficient would be undesirable because of the consequent reduction in the running speed of the torpedo. However, if the increase in the drag coefficient is small, the improved stability and controllability may be well worth it since the speed varies only as the cube root of the drag coefficient. That is, for a given brake horsepower, an increase in the drag coefficient of 3% would decrease the speed only 1%. Since the torpedo normally travels with small pitch angles (1° or less), and since the drag varies but little with pitch angle, we shall use, in this discussion, the drag coefficient at zero pitch as a measure of the effect of shroud rings on the drag.

An inspection of the drag coefficient curves shows that, of the 16° conical rings, the 1-1/4" and 7/8" rings increase the drag by 18% for the 10° rudder setting, while the 1/2" ring increases it by only 5%. The cylindrical rings increase the drag by 10 to 25%. The 8° conical rings cause the least increase in drag, not more than about 3-1/2%. The one curve for the 1/2", 8° ring, which shows an increase in drag of about 10%, may be



MK 13-1 TORPEDO WITH TOROGIVAL TAIL
EFFECT OF SHROUD WIDTH ON STABILITY
ALL RUDDERS NEUTRAL

FIGURE 22

in error since it is in disagreement with all other drag data on the 8° conical rings.

It is seen, therefore, that when the ring fits the flow lines its effect on the drag is slight. When the ring does not fit the flow lines, that is, when it causes the flow lines either to converge or to diverge, the drag is appreciably increased.

RUDDER EFFECT AS FUNCTION OF SHROUD WIDTH

Referring to Figure 21 again, it is seen that all the rings tested reduce the rudder effect, and that this reduction is nearly independent of cone angle but is affected mainly by ring width. Taking the 16° shrouds as an example we see that the 1-1/4" ring reduces the rudder effect from -.053 to -.010, or to about 19% of its value without ring, but with the narrower rings the decrease of rudder effect is smaller. The 1/2" ring reduces the rudder effect only to 62% of its former value. The reduction in the effectiveness of the rudders is partly due to the fact that some of the water deflected by the rudders is deflected back toward its former direction by the ring. In the case of these models, the rudder effect was further reduced because the actual rudder area was decreased to accommodate the rings. Also, the reduction in area was made at the outer edges of the rudders, where they are most effective because the velocity there is greater than it is nearer the body. It is believed that, with the half-inch rings, the rudder effect would not have been materially affected by the shroud had the rudder area been equal to that of the torpedo without ring.

It should be noted that the location of the trailing edge of the ring with respect to the rudders, rather than the ring width, is the main factor in determining the rudder effect. That is, the influence of the ring on rudder effect depends on how far the ring extends aft of the rudder hinge. For the rings used in these tests, since their leading edges were all in the same position, the rudder effect appears as a function of ring width.

It is obvious that the widest rings tested are unsatisfactory because of the detrimental result on rudder effect. With the narrow rings, the reduction in the effectiveness of the rudders is small enough so that, if necessary, it may be compensated for by increasing the rudder areas. It should be emphasized, however, that if it is desirable to use the large shroud width, it can be done without decreasing the rudder effect, provided that the rudders are located at the trailing edge of the shroud ring, which can be accomplished by moving either the ring forward or the rudders aft.

EFFECT OF SHROUD ON CONTROL ANGLE

Further study of Figure 21 shows that the control angle may be increased or decreased by varying either the stability or the rudder effect. For any given rudder effect, decreasing the absolute value of the slope of the moment curves increases the control angle, neutral stability giving unlimited control angle. With any given degree of stability or instability, increasing the rudder effect also increases the control angle. It is seen that all three 16° conical rings reduce the control angle, but all three cylindrical rings increase it from the original value of 5 degrees (without ring) to apparently several times this value, since it goes beyond the range of measurement of the tunnel. Of the 8° conical rings, the two wider rings decrease the control angle, while the 1/2" ring increases it to well over 10 degrees.

EFFECT OF SHROUD ON THE LIFT AND CROSS-FORCE

Figures 11 to 19 show that with the 16° conical shrouds the slope of the lift coefficient curves is nearly the same as that of the torpedo without shroud tail. The 8° conical rings and the cylindrical rings cause the lift coefficient curves to become steeper. All the shroud tails tested decrease the variation of the lift coefficient with changes in rudder setting. That is, in general, to obtain a given lift a slightly larger pitch angle will be required with shroud ring than without.

This is not believed to be detrimental since with all the rings tested, except the one of 16° cone angle and 1-1/4" width, the torpedo will still be able to carry the maximum load required of the Mk 13 series (434 lbs negative buoyancy) with a pitch angle of not more than one degree (at 33.5 knots this corresponds to a lift coefficient of about 0.051).

BEHAVIOR IN THE HORIZONTAL PLANE

All tests in this series were made in the pitching, or vertical plane. Since the vertical rudders were not made movable, it was not possible to study the rudder effect and control angle in the yawing plane. However, it is safe to assume that the effect of the shrouds on stability in the horizontal plane would be about the same as in the vertical plane. Likewise, the 1-1/4" and 7/8" rings would probably affect the control angle and rudder effect in the same manner as in the vertical plane. However, it is believed that the 1/2" rings will decrease the control angle and rudder effect in the horizontal plane even less than in the vertical plane, because these short rings leave the vertical rudders completely exposed whereas the horizontal rudders are partly enveloped by them. That is, the rudder effect in the horizontal plane with the 1/2" rings may be expected to be nearly as good as it is without ring. With improved stability this would give rise to a larger control angle than obtained without ring.

V. SUMMARY

The characteristics of the Mk 13-1 torpedo with nine different shroud tails are shown in Figures 11 to 19, inclusive, and in Figures 21 and 22. Some of the shroud tails included in these preliminary tests produced marked improvements in the stability and control angle of the torpedo. The trends of variation of stability, control angle, rudder effect, and drag, as influenced by shroud ring design are clearly brought out. The results of these tests may be summarized as follows:

1. Shroud rings are effective means for increasing stability.

2. Stability increases with decreasing cone angle.

3. The effect of ring width on stability depends on the relationship between the shroud cone angle and the flow lines around the afterbody. When the shroud fits the flow lines, the stability is practically independent of the ring width within the range tested; when the shroud causes the flow lines to converge, stability increases with decreasing ring width; and when the shroud causes the flow lines to diverge, stability decreases with decreasing ring width.

4. The variation in the stability of the torpedo with the nine rings tested ranged from slightly greater instability than that of the torpedo without shroud (ring of 16° cone angle and 1-1/4" width), to neutral stability (with cylindrical ring of 1-1/4" width).

5. The rudder effect is independent of cone angle, but varies with the position of the rudders with respect to the trailing edge of the shroud ring. The more the shroud overlaps the rudders, the smaller the rudder effect. With the rings tested, since the leading edges of all rings were in the same relative position with respect to the rudders, the rudder effect varied with shroud width. All rings tested caused a reduction in the rudder effect, but with the 1/2" rings the reduction is probably not large enough to be detrimental, and if necessary, may be corrected by increasing the area of the rudders.

6. The control angle varies as a result of variations of both the stability and the rudder effect. The more nearly neutral the stability, and the greater the rudder effect, the larger the control angle. Five of the nine rings tested reduced the control angle. The three cylindrical rings, and the 8° conical of 1/2" width, increased the control angle from 5° (without ring) to well over 10 degrees.

7. The effect of the shroud rings on the lift is to decrease.

the variation of the lift coefficient with changes in rudder setting. This is not believed to be objectionable, since with eight of the nine rings tested (16° conical ring of 1-1/4" width excepted) the torpedo would still be able to carry its negative buoyancy with a pitch angle of not more than one degree.

8. All the shroud rings tested increase the drag at zero pitch. The increase of the drag coefficient over that without ring varied from 25% down to 3%. The lowest drag coefficients were obtained with the 8° conical rings, which were designed to fit the flow lines around the afterbody of the torpedo.

These tests were made on models without propellers. On propeller-driven torpedoes, the flow lines on the afterbody may be expected to converge more rapidly than they do on the model because flow on the afterbody is accelerated by the propellers. Therefore, to produce on the prototype torpedoes results similar to those found in these tests, the rings should have somewhat larger cone angles than the corresponding model rings.

With some of the rings tested, appreciable improvement in the stability and controllability of the torpedo have been obtained with only negligible increase in the drag. The best stability condition measured in these tests is neutral stability. It is believed that with further investigation along these lines, it may be possible to obtain positive stability without detriment to other characteristics, although there is still some question as to whether positive stability is desirable for a torpedo.

References:

(1) For complete description see the following report on file in the office of Section 6.1, NDRC, "The High Speed Water Tunnel at the California Institute of Technology" by R. T. Knapp, V. A. Vanoni, and J. W. Daily, June 29, 1943

APPENDIX A

TEST EQUIPMENT AND PROCEDURES

The tests covered by this report were conducted in the High Speed Water Tunnel at the California Institute of Technology. The following paragraphs contain a brief description of the tunnel and the test procedures employed. A more detailed description of the High Speed Water Tunnel will be found in Reference 1.

MAIN CIRCUIT

The Water Tunnel is of the closed circuit, closed working section type. Figure A-1 shows a profile of the main flow circuit which consists essentially of the working section, the circulating pump, the stilling tank, and the necessary pipe connections. The cylindrical working section is 14" in diameter, 72" long, and is provided with three lucite windows. The propeller-type circulating pump is V-belt connected to a variable speed dynamometer. The speed of the dynamometer is automatically controlled and is held constant within ± 1 r.p.m., which corresponds to a maximum water velocity variation in the working section of 1/30 ft. per sec. While most tests are made with water velocities of 24 to 31 ft. per sec., any velocity between 10 and 72 ft. per sec. is easily obtainable.

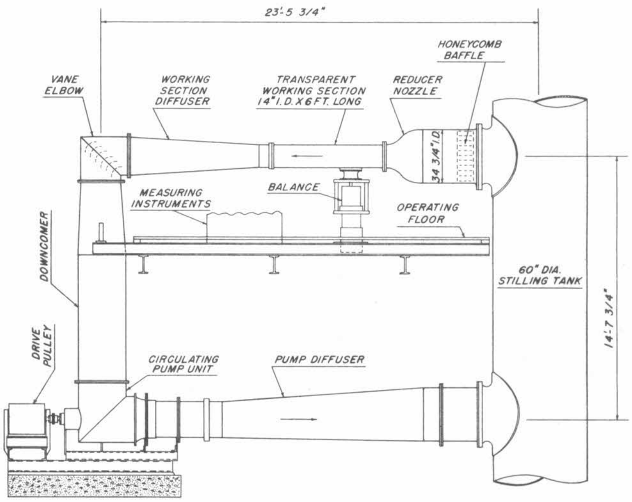


FIGURE A-1

AUXILIARY CIRCUITS

Two auxiliary water circuits, one for pressure control and one for temperature control, are used in conjunction with the main circuit. These circuits are shown in Figure A-2, which is an isometric diagram of the complete water tunnel installation.

To make it possible to induce or inhibit cavitation at will, it is necessary that the pressure in the working section be controllable independently of the velocity. This is accomplished by superimposing the pressure regulating circuit on the main circuit.

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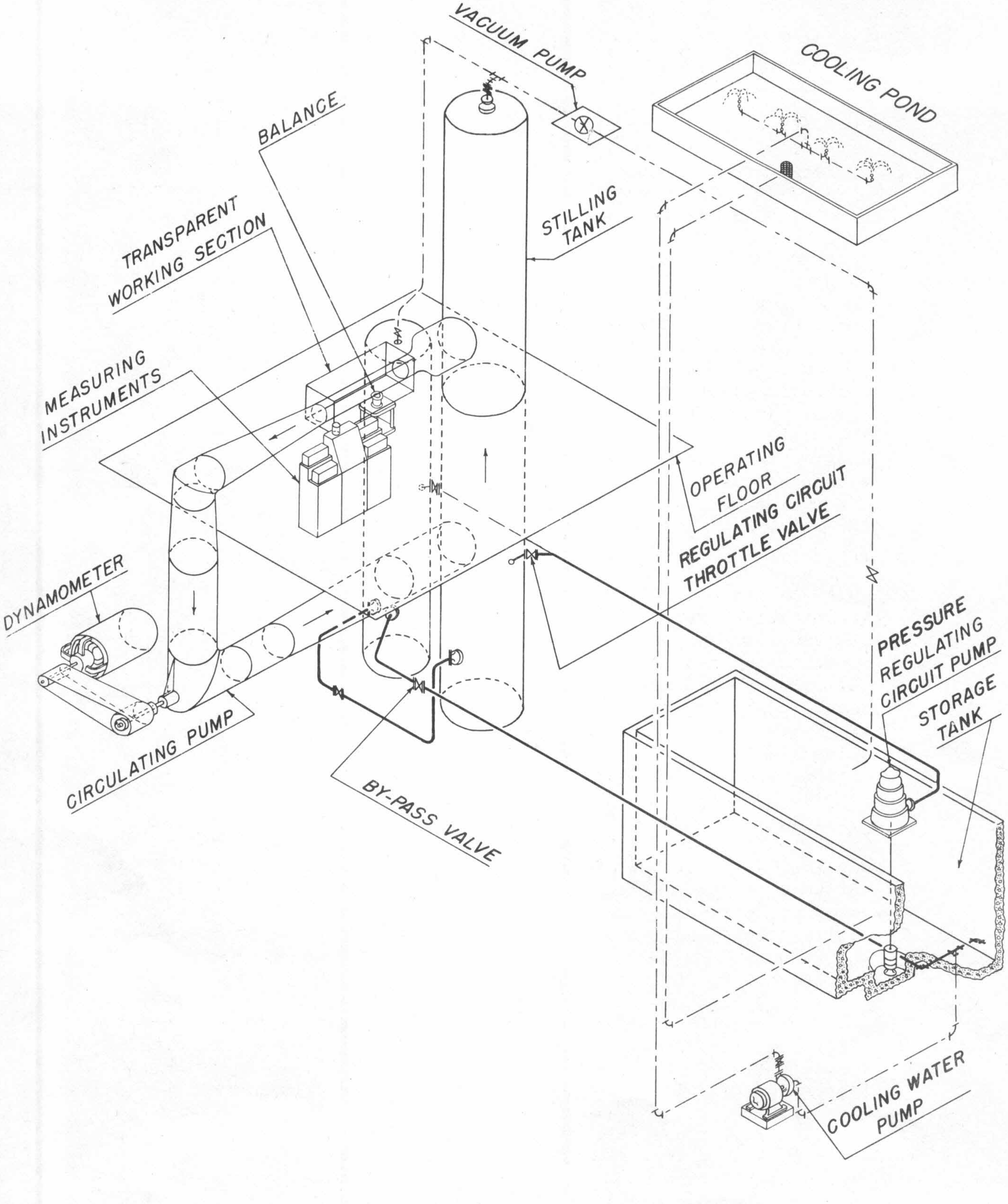

FIGURE A-2

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A small flow of water from the sump is forced into the stilling tank by the regulating pump, and is returned to the sump through the by-pass valve. Since the main circuit is closed and completely filled, it is evident that the pressure in it may be controlled by varying the opening of the by-pass valve. A stripping pump (not shown in Figure A-2), in series with the by-pass valve, is used to produce very low pressures. The vacuum pump is used to remove air from the system so as to keep it full of water at all times.

The energy put into the water of the main circuit by the circulating pump (up to 250 HP) is all dissipated in heat. To prevent the temperature of the water from rising to undesirable values, it is necessary to remove this heat by cooling. Part of the water returned through the by-pass valve is picked up by the cooling water pump, circulated through the forced-draft cooling tower on the roof, and returned to the sump. By varying the quantity of water circulated through the cooling system, it is possible to maintain the water in the main circuit at a constant temperature.

BALANCE

The balance, shown schematically in Figure A-3, is designed to measure three components of the hydrodynamic forces acting on the model. These are the drag force parallel to the flow, the cross-force normal to the flow, and the moment around the axis of support. The three forces to be measured are transmitted hydrostatically to three self-balancing, weighing type pressure gages. These automatic gages, under glass covers, may be seen in Figure A-4, which is a view of the operating floor of the Water Tunnel. The fourth gage shown in this figure is a weighing type manometer used to determine the velocity in the working section by measuring the pressure drop across the reducing nozzle. The gages are responsive to a change in the drag or cross-force acting on the model of 0.02 pounds, and a change of 0.04 inch-pounds in the moment.

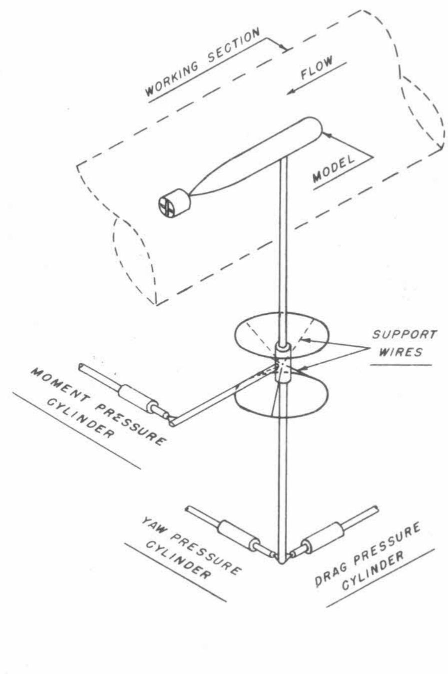

FIGURE A-3

The model is mounted on a shaft which forms the core of the vertical balance spindle shown in Figure A-3. By rotating this shaft within the spindle, it is possible to change the orientation of the model with respect to the direction of flow without altering the direction of the force components measured. Between adjustments, the spindle and shaft are held firmly together by a long, spring-loaded, tapered seat. To change the adjustment, the taper is unseated by an air diaphragm and the shaft is rotated through a worm and gear-sector by a small electric motor (not shown in the figure) mounted on the spindle. A Veeder counter on the worm gear shaft indicates the angle of attack to the nearest 1/10 degree. It should be noted that this whole system forms a part of the spindle assembly, which is pivoted about the point of intersection of the support wires. Thus it does not affect the force measurements in any way.

To reduce the drag tare to a minimum, the portion of the spindle shaft which projects into the working section is protected from the flow by a streamlined shield which extends to within a few thousandths of an inch of the model.

POLARIZED LIGHT FLUME

The Polarized Light Flume is a separate piece of equipment used for studying the flow around submerged bodies. The fluid circulated is water containing 0.2 per cent by weight of Bentonite in suspension. Bentonite has the asymmetrical optical and physical properties required for the production of streaming double refraction. The flow to be studied is made visible by projecting a beam of light across it through a pair of polaroid plates which are oriented to produce a dark field when there is no flow. The observation section is a rectangular channel 6" wide and 12" deep, having glass sides and bottom.

The velocities used in this flume are necessarily lower than those employed in the High Speed Water Tunnel. However, this difference is not sufficient to affect the validity of the flow patterns observed. A knowledge of these flow patterns is found to be of assistance in the interpretation of the dynamic behavior of the projectiles studied. It is very helpful in investigating interference phenomena, the cause and location of separation or flow instabilities, and the behavior of the boundary layer. Care must be exercised in interpreting the observed patterns, both because the flow is three-dimensional, whereas the observed optical effect is an integration of the entire path of the light beam, and because the pattern produced is a shear pattern and not one of streamlines.

TEST PROCEDURES

The facilities of the High Speed Water Tunnel provide for great flexibility in operation and test procedures. Individual test runs are usually made to determine the effect on the hydrodynamic forces of individual variables, although any of the variables may be changed at will independently of the others.

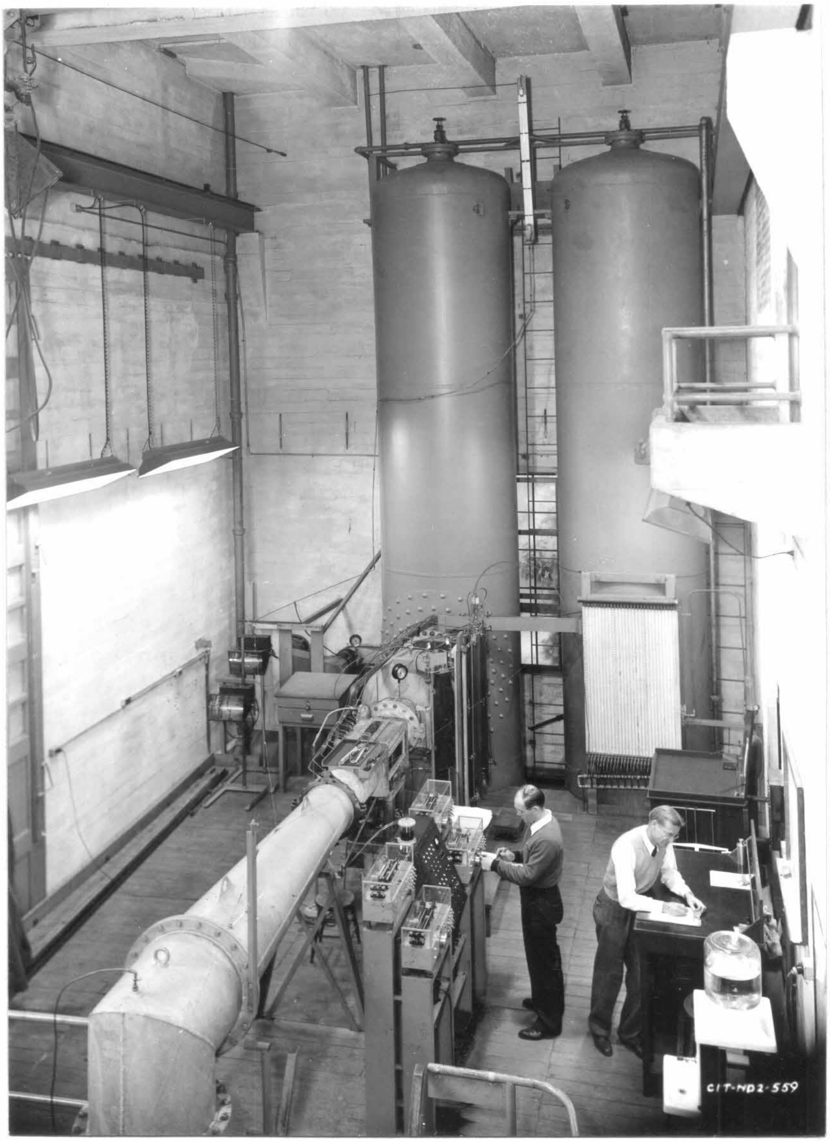

FIGURE A-4

OPERATING FLOOR
OF THE
HIGH SPEED WATER TUNNEL

Constant-velocity test runs are made to determine the variation of the hydrodynamic forces with changes in the orientation of the projectile with respect to the line of flow. The angle of attack is changed in steps of 1/2 or 1 degree, and the three force components are measured at each step.

A single test, covering the desired range of angles of attack is sufficient to completely determine the yawing characteristics of a projectile which is symmetrical about its longitudinal axis and has no movable control surfaces. A projectile which is not symmetrical about its longitudinal axis (e.g., having unequal horizontal and vertical fins) will show different characteristics when yawed in different planes and, therefore, must be tested in more than one plane. Since the model can be yawed only in a plane normal to the spindle, this is accomplished by making several separate test runs, with the model mounted on the spindle in a different orientation for each run. For instance, one run with vertical fins in a vertical position and another with horizontal fins in a vertical position. These would correspond to a yawing test and a pitching test, respectively. For a projectile with movable rudders, several tests are made, each with the rudders set at a different angle.

Cavitation is an important factor in the behavior of underwater projectiles travelling at high speed near the surface. To determine the cavitation characteristics of such a projectile, separate tests are made during which the pressure is varied while all the other factors are held constant. The inception and development of cavitation may be observed or photographed through the transparent windows of the working section, and the velocities and pressures at which cavitation begins on the various parts of the projectile are measured.

Variable-speed test runs are made to determine the scale (Reynolds number) effect on the hydrodynamic forces. The speed is usually varied in 5 fps steps and the forces are measured at each step. The pressure in the working secgion is kept high enough to suppress cavitation at the highest velocity.

APPENDIX B

DEFINITIONS

PITCH ANGLE

The angle in the vertical plane which the axis of the projectile makes with the direction of travel. Pitch angles are positive (+) when the nose is up, and negative (-) when the nose is down.

YAW ANGLE

The angle in the horizontal plane which the axis of the projectile makes with the direction of travel. Looking down on the projectile and in the direction of travel, yaw angles to the right are positive (+), and to the left, negative (-).

LIFT

The force, in pounds, exerted on the projectile in a direction normal to the line of travel and in the vertical plane, positive (+) when acting upward, and negative (-) when acting downward.

CROSS FORCE

The force, in pounds, exerted on the projectile in a direction normal to the line of travel and in the horizontal plane. A positive cross force is defined as one acting in the same direction as the displacement of the projectile nose for a positive yaw angle.

DRAG

The force, in pounds, exerted on the projectile in a direction parallel with the line of travel. The drag is positive when acting in a direction opposite to the direction of travel.

MOMENT

The torque tending to rotate the projectile about a transverse axis. A positive or clockwise moment tends to increase a positive yaw or pitch angle. A moment, therefore, has a destabilizing effect when it has the same sign as the yaw or pitch angle, and a stabilizing effect when of opposite sign.

COEFFICIENTS

The force and moment coefficients are defined as follows:

Lift Coefficient, $$C_L = \frac{L}{1/2\ \rho\ V^2 A}$$

Cross Force Coefficient, $$C_C = \frac{C}{1/2\ \rho\ V^2 A}$$

$$\text{Drag Coefficient,} \quad C_D = \frac{D}{1/2\ \rho\ V^2 A}$$

$$\text{Moment Coefficient,} \quad C_M = \frac{M}{1/2\ \rho\ V^2 A l}$$

where

L = lift force, pounds

C = cross force, pounds

D = drag force, pounds

M = moment, foot-pounds

ρ = density of water, slugs per cu. ft.

V = velocity, feet per second

A = area of a crossection taken normal to the longitudinal axis of the projectile at its maximum diameter, square feet

l = overall length of projectile, feet

REYNOLDS NUMBER $$R_e = \frac{Vl\rho}{\mu} = \frac{Vl}{\nu}$$

where

V, l, and ρ are defined above, and

μ = absolute viscosity of water, pound-second per square foot

$\nu = \frac{\mu}{\rho}$ = kinematic viscosity of water, square feet per second

CAVITATION PARAMETER $$K = \frac{P - P_V}{1/2\ \rho\ V^2}$$

where

ρ and V are as defined above, and

P = absolute pressure in water surrounding the projectile, pounds per square foot

P_V = vapor pressure of water, pounds per square foot